PhytoKeys

PhytoKeys 247: 29–38 (2024)
DOI: 10.3897/phytokeys.247.132538

Research Article

Resurrection of *Sorbus tapashana* (Rosaceae) based on molecular and morphological evidence

Xin Chen[1], Wen-Xiang Hou[1], Jun-Ling Hu[1], Meng-Die Dong[1], Bao-Mei Tan[1]

1 *Co-Innovation Center for Sustainable Forestry in Southern China, College of Life Sciences, Nanjing Forestry University, Nanjing, China*
Corresponding author: Xin Chen (chenxinzhou@njfu.edu.cn)

Abstract

Sorbus tapashana (Rosaceae) from Taibai Shan, Qinling, China, has been treated as a synonym of *S. tianschanica*. Both species belong to a distinctive group characterized by white tomentose buds, relatively large flowers, and red fruits. However, these two species do not cluster together in the plastome-based phylogenetic analysis. Morphologically, *S. tapashana* differs from *S. tianschanica* by its persistent white tomentose on the peduncle, pedicels, rachis, both sides of the midrib on abaxial surface, its leaflets with 31–51 teeth on each side and much smaller corymbs and fruits. Therefore, *S. tapashana* is reinstated as a distinct species here.

Key words: Morphological data, plastome, *Sorbus*, synonym, taxonomy

OPEN ACCESS

Academic editor: Bin-Bin Liu
Received: 25 July 2024
Accepted: 2 September 2024
Published: 3 October 2024

Citation: Chen X, Hou W-X, Hu J-L, Dong M-D, Tan B-M (2024) Resurrection of *Sorbus tapashana* (Rosaceae) based on molecular and morphological evidence. PhytoKeys 247: 29–38. https://doi.org/10.3897/phytokeys.247.132538

Copyright: © Xin Chen et al.
This is an open access article distributed under terms of the Creative Commons Attribution License (Attribution 4.0 International – CC BY 4.0).

Introduction

Sorbus L. sensu stricto (Maleae, Rosaceae) comprises approximately 90 species of trees and shrubs (Phipps et al. 1990; McAllister 2005). The genus is confined to the Northern Hemisphere, with its distribution spanning Europe, Asia, and northern North America (McAllister 2005). Morphologically, *Sorbus* s.s. can be distinguished from other genera in Maleae by its imparipinnate leaves and relatively small fruits with persistent sepals and styles. This genus exhibits high diversity in China, particularly in the southwestern mountainous regions (Lu and Spongberg 2003).

The monophyly of *Sorbus* s.s. has been confirmed by recent phylogenetic studies (Campbell et al. 2007; Liu et al. 2019, 2020, 2022, 2023a, 2023b; Jin et al. 2023, 2024). However, the circumscription of species within this genus remains unclear, particularly for those native to China (Lu and Spongberg 2003; McAllister 2005). For instance, there is debate regarding the taxonomic status of *Sorbus tapashana* C.K.Schneid. (Schneider 1906). This species has been recognized in numerous floristic and taxonomic works (Yü and Lu 1974; Gabrielian 1978; Phipps et al. 1990; Lu and Spongberg 2003) before being treated as a synonym of *S. tianschanica* Rupr. (Ruprecht 1869) by McAllister (2005). McAllister proposed that *S. tapashana* and *S. tianschanica* were conspecific, despite differences such as the denser white hairs on buds and leaflets of *S. tapashana*. However, based on our examinations of the protologues (Ruprecht 1869;

Schneider 1906), type specimens, and specimens collected from the type localities, we hypothesize that *S. tapashana* may be a distinct species.

In this study, we integrate phylogenetic inference with extensive morphological data to reevaluate the relationship between *Sorbus tapashana* and *S. tianschanica*. Our aims are to: (1) determine whether *S. tapashana* and *S. tianschanica* represent two distinct species, and (2) assess the phylogenetic relationships among *S. tapashana*, *S. tianschanica*, and other species within the genus *Sorbus* s.s.

Materials and methods

Taxon sampling

Leaf samples of *Sorbus tapashana* (China, Shaanxi, Taibai Shan, September 7, 2023, *Xin Chen 2255*, *2257*) and *S. tianschanica* (Xinjiang, July 10, 2020, *Wenhao Fan 1761*) were collected from their type localities, Taibai Shan and Tianshan, respectively. Voucher specimens are deposited in the Herbarium of Nanjing Forestry University (**NF**).

DNA extraction, sequencing, and genome assembly

Whole genomic DNA was isolated from silica-gel dried leaves using a modified CTAB method (Doyle and Doyle 1987). Short-insert (150 bp) paired-end libraries were prepared for genome skimming using the Illumina HiSeq 4000 sequencing platform at Beijing Genomics Institute (BGI, Shenzhen, China). De novo assembly was performed using GetOrganelle v.1.7.5.3 (Jin et al. 2020) with *Torminalis glaberrima* (NC033975) as a reference. Genomes were annotated using the PGA program (Qu et al. 2019) with *S. tianschanica* (ON049666) as a reference. Annotation errors were manually verified and corrected using Geneious v.9.0.2 software (Kearse et al. 2012).

Phylogenetic analysis

The plastome dataset alignment for this study includes 41 individuals representing 37 *Sorbus* s.s. taxa. This dataset comprises three newly sequenced samples: two from *S. tapashana* and one from *S. tianschanica*, alongside 38 accessions sourced from GenBank (www.ncbi.nlm.nih.gov/genbank). *Photinia prionophylla* (Franch.) C.K.Schneid. was used as the outgroup for phylogenetic analyses. GenBank accession numbers utilized in this study are listed in Table 1.

The plastid genome dataset was aligned using MAFFT v.7.388 (Katoh and Standley 2013) within Geneious v.9.0.2, followed by manual adjustments. Phylogenetic relationships were inferred using both maximum likelihood (**ML**) and Bayesian inference (**BI**). ML analyses, employing the GTR+G nucleotide substitution model, were estimated with RAxML v.8.2.10, with 100 runs and 1,000 bootstrap (**BS**) Ronquist and Huelsenbeck 2003replicates (Stamatakis 2014). BI analyses were performed using MrBayes v.3.2.7 (Ronquist and Huelsenbeck 2003), running the Markov chain Monte Carlo (MCMC) for 2,000,000 generations with trees sampled every 1000 generations. The resulting trees from ML and BI analyses were visualized using FigTree v.1.4.3 (http://tree.bio.ed.ac.uk/software/figtree).

Table 1. Taxon name and GenBank accession numbers for all individuals included in this study.

Taxon	Genbank accession number	Taxon	Genbank accession number
Photinia prionophylla (Franch.) C.K.Schneid.	NC045355.1	*Sorbus pohuashanensis* (Hance) Hedl.	OP613257.1
Sorbus aestivalis Koehne	NC068530.1	*Sorbus poteriifolia* Hand.-Mazz.	OR915972.1
Sorbus albopilosa T.T.Yu & L.T.Lu	OR915913.1	*Sorbus prattii* Koehne	NC085635.1
Sorbus amabilis Cheng ex T.T.Yu & K.C.Kuan	MT357029.1	*Sorbus randaiensis* (Hayata) Koidz.	NC085665.1
Sorbus aucuparia L.	OR915953.1	*Sorbus rehderiana* Koehne	OR915914.1
Sorbus californica Greene	NC085651.1	*Sorbus rufopilosa* C.K.Schneid.	NC085638.1
Sorbus commixta Hedl.	MK920288.1	*Sorbus sambucifolia* (Cham. & Schltdl.) M.Roem.	NC085654.1
Sorbus decora (Sarg.) C.K.Schneid.	NC085652.1	*Sorbus sargentiana* Koehne	OR915977.1
Sorbus discolor (Maxim.) Maxim.	OR915986.1	*Sorbus scalaris* Koehne	NC085637.1
Sorbus dumosa House	NC085653.1	*Sorbus scopulina* Hough	NC085658.1
Sorbus helenae Koehne	NC068536.1	*Sorbus setschwanensis* (C.K.Schneid.) Koehne	NC046777.1
Sorbus himalaica Gabrieljan	NC085572.1	*Sorbus sibirica* (Hedl.) Prain	NC085576.1
Sorbus hupehensis var. *hupehensis* C.K.Schneid.	NC068721.1	*Sorbus sitchensis* var. *grayi* (Wenz.) C.L.Hitchc.	OR897861.1
Sorbus hupehensis var. *paucijuga* (D.K.Zang & P.C.Huang) L.T.Lu	MT916771.1	*Sorbus tapashana* C. K.Schneid.	PQ031218; PQ031219
Sorbus insignis (Hook.f.) Hedl.	NC051947.1	*Sorbus tianschanica* Rupr.	PQ031217
Sorbus kiukiangensis T.T.Yu	NC085636.1	*Sorbus tianschanica* Rupr.	MK920289.1
Sorbus kiukiangensis T.T.Yu	OR915919.1	*Sorbus tianschanica* Rupr.	ON049666.1
Sorbus macrantha Merr.	NC085631.1	*Sorbus tianschanica* Rupr.	OK375442.1
Sorbus microphylla (Wall. ex Hook. f.) Wenz.	NC085633.1	*Sorbus ulleungensis* Chin S.Chang	MG011706.1
Sorbus munda Koehne	NC062714.1	*Sorbus unguiculata* Koehne	MK814479.1
Sorbus oligodonta (Cardot) Hand.-Mazz.	NC085634.1	*Sorbus wilsoniana* C.K.Schneid.	OR915983.1

Morphological analysis

Morphological characters were examined using our specimens and online images from various sources including herbaria A, HNWP, IBK, IBSC, IFP, KUN, LBG, NAS, NWTC, PE, and XBGH. These images were accessed through the Chinese Virtual Herbarium (http://www.cvh.ac.cn/), JSTOR Global Plants (https://plants.jstor.org/), the Global Biodiversity Information Facility (GBIF; https://www.gbif.org/), and the Plant Photo Bank of China (PPBC; http://ppbc.iplant.cn/). Measurements were taken from both actual specimens and those with scale bars in the images.

Results and discussion

Phylogenetic analyses

The phylogenetic trees inferred from ML and BI methods were topologically congruent, with only minor differences in support values. Consequently, only the ML tree is presented here, with support values from both ML and BI analyses indicated at each node (Fig. 1).

Our results strongly support the monophyly of *Sorbus* s.s., which is divided into two major clades (Fig. 1: I and II). Clade I includes 14 species and two varieties within *S.* subg. *Sorbus*, excluding *S. hupehensis* var. *paucijuga* (D.K.Zang & P.C.Huang) L.T.Lu. Clade II contains *S. tianschanica* and species from *S.* subg. *Albocarmesinae* McAll., with *S. tapashana* deeply nested within it. Notably, *S. tapashana* is distantly related to *S. tianschanica*.

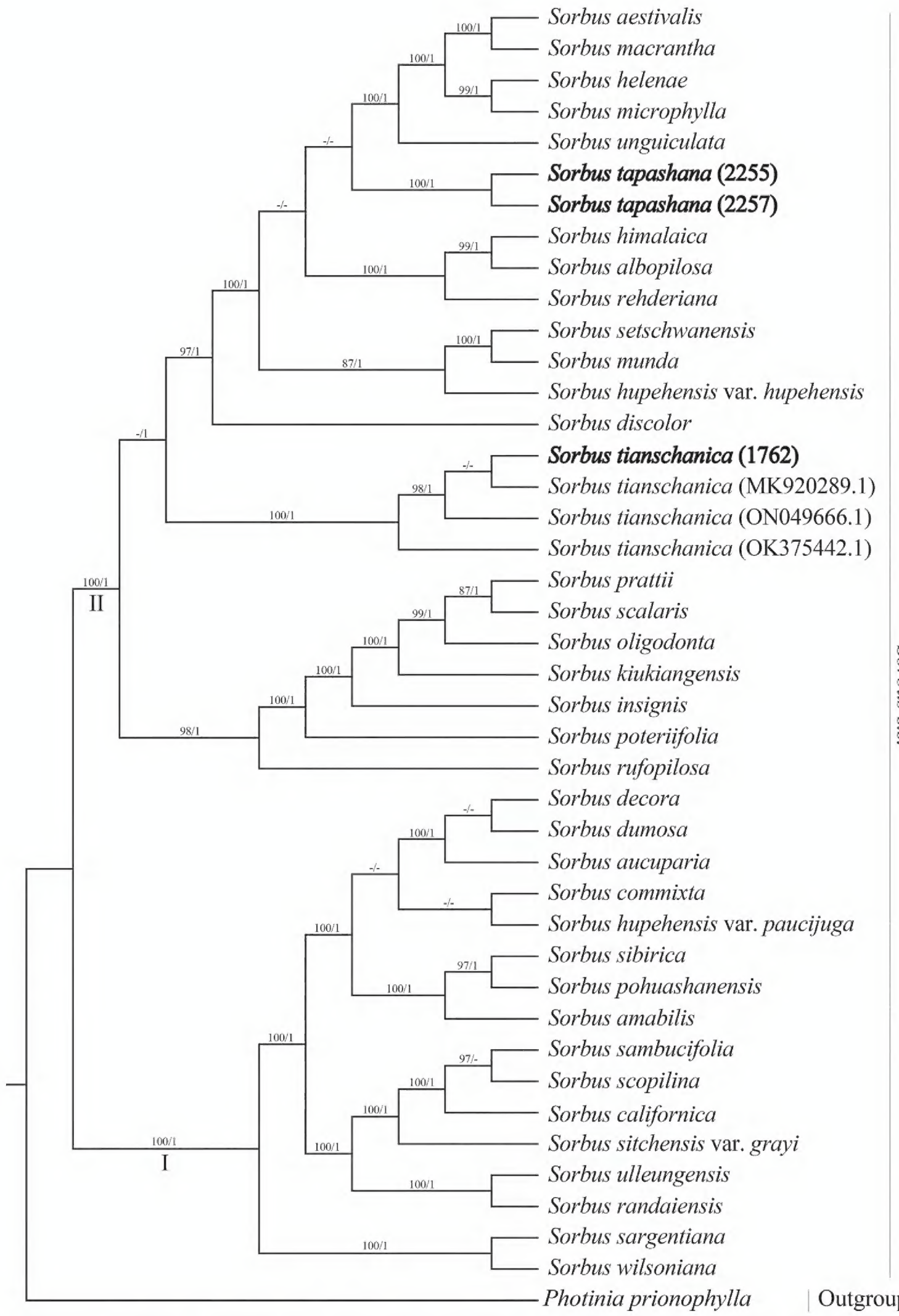

Figure 1. Phylogenetic tree of *Sorbus* s.s. resulting from the maximum likelihood analysis and Bayesian inference of the plastome data set. Numbers below the branches indicate bootstrap values (≥70%) of the ML analyses and the posterior probability (≥0.95) of Bayesian analyses.

Our findings unequivocally demonstrate the existence of two distinct, well-resolved clades within the monophyletic *Sorbus* s.s., which broadly align with the two subgenera proposed by McAllister (2005). However, contrary to previous classifications that placed *S. tianschanica* within subg. *Sorbus* due to its uniformly red fruits, our data show that it is embedded in clade II along with species from subg. *Albocarmesinae*, consistent with other recent molecular studies (Li et al. 2017; Tang et al. 2022; Wang et al. 2024). While the plastome dataset analyses show

Table 2. Comparison of morphological characters, phenologies, and distributions of *Sorbus tapashana* and *S. tianschanica*.

	Sorbus tapashana	***Sorbus tianschanica***
Branchlets	brownish or grayish brown, terete, lenticellate	
Buds	white pubescent	
Leaves	9–18 cm in length	14–17 cm in length
Petiole	1.5–4.1 cm long	1.5–4.3 cm long
leaflets	(4–)5–7 pairs	(4–)6–7 pairs
The number of teeth on each side of the leaflet	31–51	12–24
Stipules	linear-lanceolate, 5–7 mm, caducous	linear-lanceolate, 7–11 mm, caducous
Inflorescences	5–9 × 5–8 cm, with persistent white pubescent	6–10 × 7–12(–15) cm, sub-glabrous
Flowers	1.5–2 cm in diameter	1.5–1.8(–2.0) cm in diameter
Styles	usually 5, densely white tomentose basally	(3–)5, densely white tomentose basally
Fruit	red, globose, 8–10 mm in diameter	scarlet, globose, 1–1.2 cm in diameter
Phenology	flowering in June; fruiting in September	flowering in May and June, fruiting in September and October
Distribution	Gansu, Shaanxi	Afghanistan, China (Gansu, Qinghai, and Xinjiang), Kazakhstan, Kirgizstan, Pakistan, Tadzhikistan, and Uzbekistan.

that *S. tapashana* and *S. tianschanica* are located in the same clade, they are isolated in different groups. *Sorbus tapashana* is more closely related to *S. aestivalis* Koehne, *S. macrantha* Merr., *S. helenae* Koehne, *S. microphylla* (Wall. ex Hook.f.) Wenz., and *S. prattii* Koehne than to *S. tianschanica*. Given that monophyly is a widely accepted as criterion for taxonomic classification (Chiarini et al. 2022; Böhnert et al. 2023), *S. tapashana* should be recognized as a distinct species.

Morphological analyses

Sorbus tapashana and *S. tianschanica* share several characters, including white tomentose winter buds, 5–7 pairs of leaflets, large flowers (1.5–2 cm in diameter), usually five and densely white tomentose styles, and red fruits (Table 2, Figs 2, 3). Consequently, both species were previously placed under ser. *Tianschanicae* Kom. ex T.T.Yü by Yü and Kuan (1963), Gabrielian (1978), and Phipps et al. (1990). Later, McAllister (2005) merged them as a single species. However, *S. tapashana* can be distinguished from *S. tianschanica* by several morphological characters (Table 2), e.g., more densely serrate leaflets (31–51 teeth per side compared to 12–24 teeth in *S. tianschanica*; Fig. 3: A2, B2), persistent white tomentose on the peduncle and pedicels (vs. sub-glabrous in *S. tianschanica*; Fig. 3: A3, B3), smaller inflorescences (5–9 × 5–8 cm compared to 6–10 × 7–12(–15) cm), and smaller fruits (8–10 mm vs. 10–12 mm in diameter; Fig. 3: A4, B4). Additionally, *S. tapashana* is restricted to Gansu and Shaanxi, China, whereas *S. tianschanica* has a much broader distribution area (Table 2).

Taxonomic treatment

Sorbus tapashana C.K.Schneid. in Bull. Herb. Boissier, sér. 2, 6: 313 (1906)

≡ *Pyrus tapashana* (C.K.Schneid.) M.F.Fay & Christenh. in Global Fl. 4: 123 (2018).

Type. China • Shaanxi: the summit of Taibai Shan, 10–20 September 1897, *Giraldi 5126* (lectotype, designated here: A[A00046062 (the upper left part)] image!).

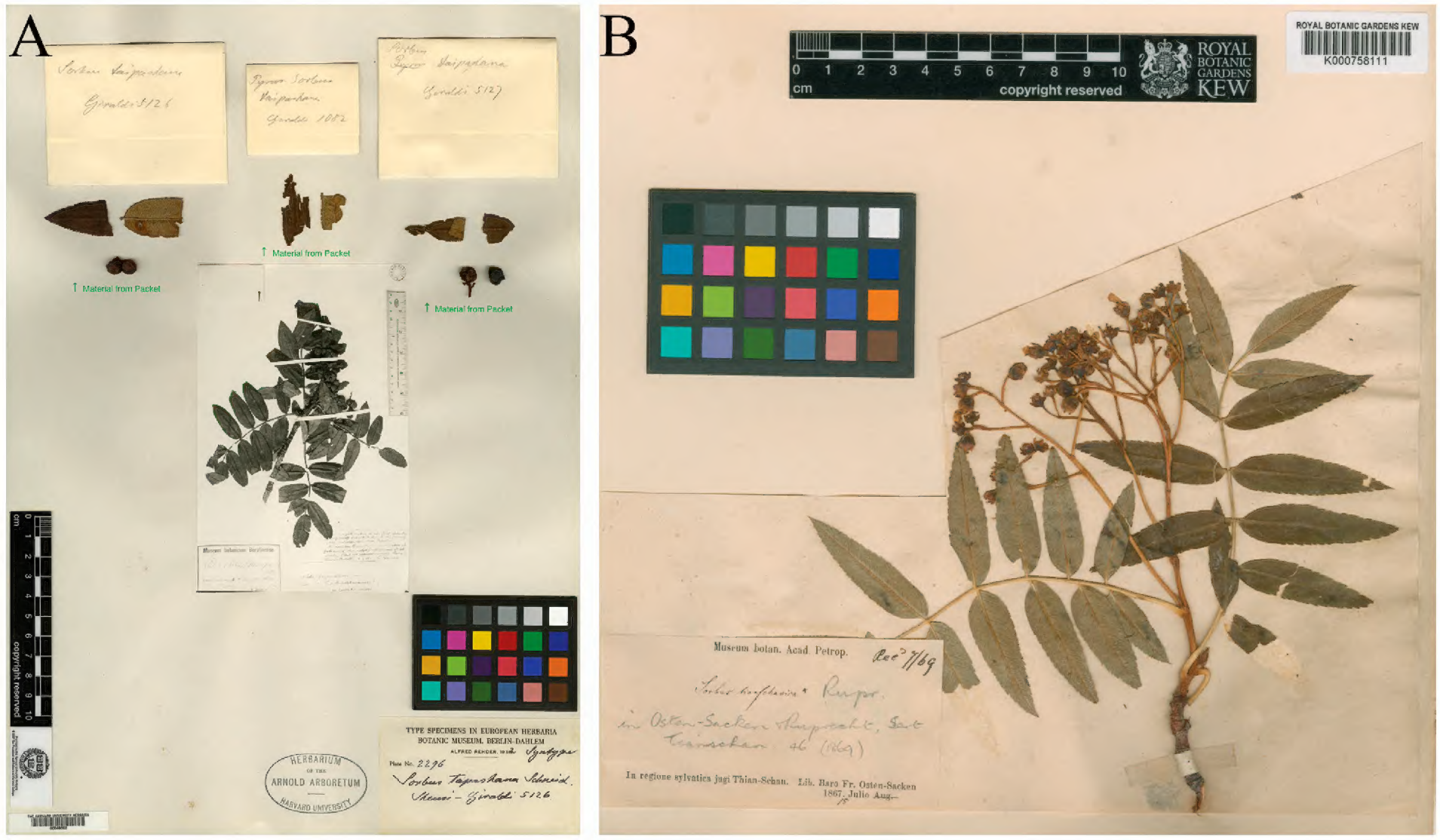

Figure 2. Lectotype of *Sorbus tapashana* C.K.Schneid. (the upper left part of A00046062) and isotype of *S. tianschanica* Rupr. (K000758111).

Note. *Sorbus tapashana* was first described by Schneider (1906). It was later transferred to the genus *Pyrus* L. s.l. along with other species from *Sorbus* sensu lato by Christenhusz et al. (2018). However, *Pyrus* s.l. has proven to be overly inclusive and polyphyletic (Liu et al. 2019, 2022; Tang et al. 2022; Jin et al. 2024; Wang et al. 2024).

When *Sorbus tapashana* was described, Schneider (1906) cited three syntypes, *Giraldi 5126*, *5127*, and *1082*, deposited in the Berlin Herbarium (B). However, none of them could be located at B. In the herbarium of the Arnold Arboretum, Harvard University (A), duplicates of these gatherings are present. At A, we found the original materials of these gatherings on Plate no. 2296. The sheet, with barcode A00046062 (image available at: HUH - Databases - Specimen Search (harvard.edu)), bears a photo of specimen “Giraldi n. 5126” at B, and three fragments belonging to *Giraldi 5126*, *5127* and *1082* respectively (Fig. 1A). The photo of *Giraldi 5126* is a fruit specimen, with scale bars and three labels on it. One of the three is the determination label of Schneider, with “*Sorbus tapashana*, an var. *S. pohuashanensis*?” on it, the same as those that had been stated in the protologue. *Giraldi 5126* is a good candidate to serve as lectotype because: (1) there is a photo of complete specimen from herbarium B which bears Schneider’s annotation; (2) the fragmentary material of *Giraldi 5126* has a leaflet (clearly showing the white tomentose persistent along the mid-vein abaxially) and two fruits. Therefore, we designate *Giraldi 5126* (the upper left part of A00046062) as the lectotype for the name.

In the protologue, it is implied that *Sorbus tapashana* may be a variety of *S. pohuashanensis* (Hance) Hedl. However, it is distinguished from the latter in having much larger flowers (1.5–2 cm in diameter), deciduous linear-lanceolate stipules (vs. relatively small flowers 5–8 mm in diameter, persistent

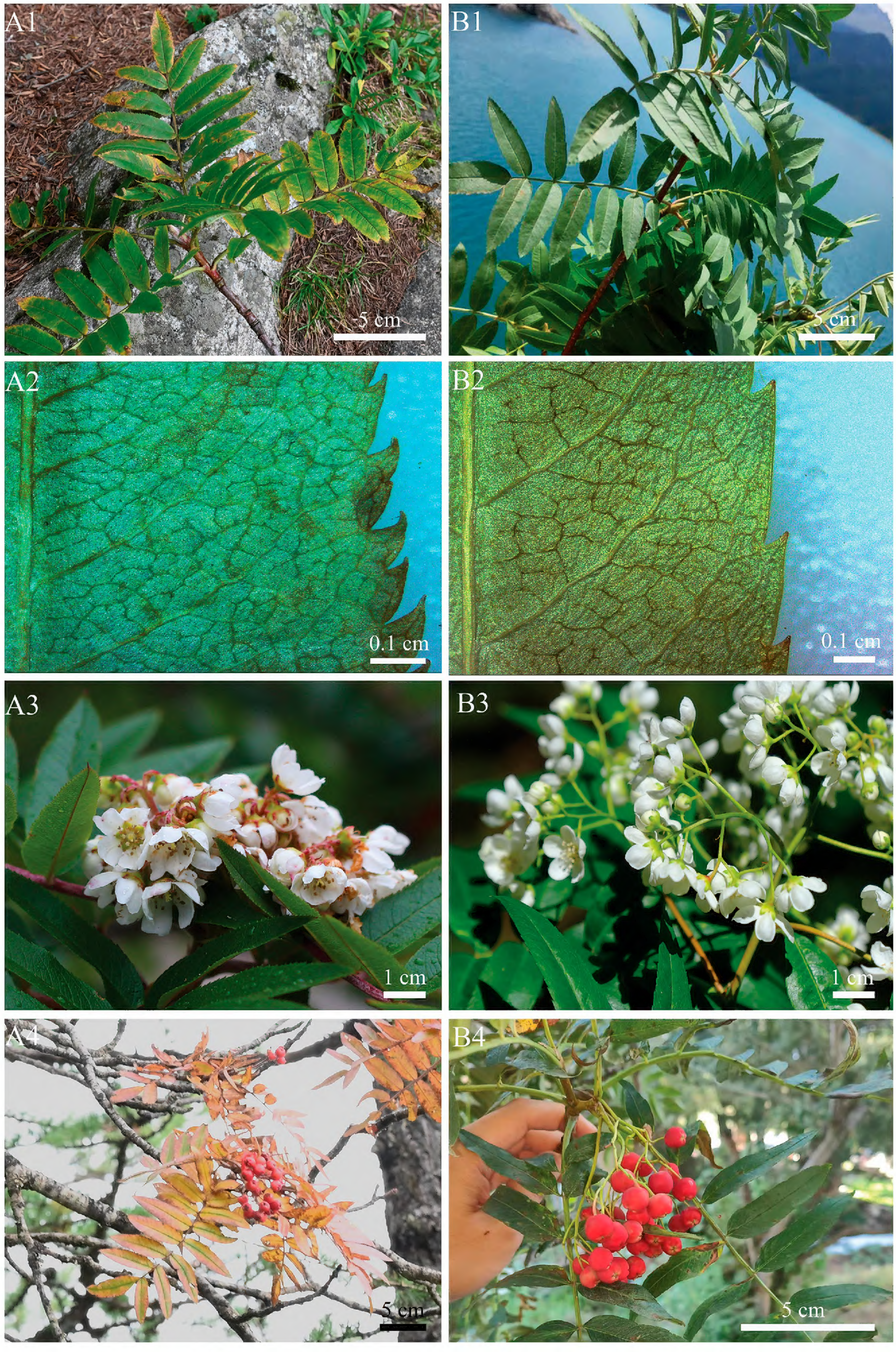

Figure 3. Comparison of morphological characters *Sorbus tapashana* C.K.Schneid. (**A1–A4**) and *S. tianschanica* Rupr. (**B1–B4**) **1** sterile branch showing leaves and buds (**B2** were taken by Wenhao Fan) **2** leaflet margins **3** corymbs (**A3** and **B3** were taken by Renbin Zhu and Yongfu Xu, respectively) **4** fertile branch showing fruits (**B4** were taken by Wenhao Fan).

broadly ovate or semi-orbicular stipules). Furthermore, *S. tapashana* is resolved in clade II while *S. pohuashanensis* in subclade I. Therefore, *S. tapashana* and *S. pohuashanensis* are separate species.

Acknowledgements

We thank the curators and staff of A, HNWP, IBK, IBSC, IFP, KUN, LBG, NAS, NWTC, PE, and XBGH for making their collections available. Many thanks go to Prof. Yunfei Deng (IBSC), Zhengyang Niu, the editor and the reviewers for their valuable comments and suggestions on the manuscript. We also thank Wenhan Fan for collecting the samples of *Sorbus tianschanica*, Renbin Zhu and Yongfu Xu for providing the photographs of *S. tapashana* and *S. tianschanica*, respectively.

Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

Funding

This work was supported by the Natural Science Foundation of Jiangsu Province (grant no. BK20141472).

Author contributions

Conceptualization: XC. Data curation: WXH, MDD. Funding acquisition: XC. Investigation: XC. Methodology: XC. Software: WXH, HJL. Validation: BMT. Writing – original draft: XC. Writing – review and editing: XC.

Author ORCIDs

Xin Chen https://orcid.org/0000-0003-2315-083X
Wen-Xiang Hou https://orcid.org/0000-0001-6928-5321
Jun-Ling Hu https://orcid.org/0009-0007-4527-0767
Meng-Die Dong https://orcid.org/0009-0004-1932-4950
Bao-Mei Tan https://orcid.org/0009-0000-8582-2780

Data availability

All of the data that support the findings of this study are available in the main text.

References

Böhnert T, Neumann M, Quandt D, Weigend M (2023) Phylogeny based generic reclassification of *Muscari* sensu lato (Asparagaceae) using plastid and genomic DNA. Taxon 72(2): 261–277. https://doi.org/10.1002/tax.12864

Campbell CS, Evans RC, Morgan DR, Dickinson TA, Arsenault MP (2007) Phylogeny of subtribe Pyrinae (formerly the Maleae, Rosaceae): Limited resolution of a complex evolutionary history. Plant Systematics and Evolution 266 (1–2): 119–145. https://doi.org/10.1007/s00606-007-0545-y

Chiarini FE, Deanna R, Bohs L (2022) Phylogeny, character evolution and biogeography of the genus *Sclerophylax* (Solanaceae). Taxon 71(6): 1251–1267. https://doi.org/10.1002/tax.12796

Christenhusz MJM, Fay MF, Byng JW [Eds] (2018) The global flora. A practical flora to vascular plant species of the world. – Special Edition, GLOVAP Nomenclature Part 1, Vol. 4: 1–155. Plant Gateway Ltd., Bradford.

Doyle JJ, Doyle JL (1987) A rapid DNA isolation procedure for small quantities of fresh leaf tissue. Phytochemical Bulletin 19: 11–15. https://doi.org/10.12691/ajmr-3-1-7

Gabrielian E (1978) The genus *Sorbus* L. in Western Asia and the Himalayas. Academy of Sciences of the Armenian SSR, Erevan, USSR, 264 pp.[+ 62 plates] [In Russian, with English summary]

Jin JJ, Yu WB, Yang JB, Song Y, de Pamphilis CW, Yi TS, Li DZ (2020) GetOrganelle: a fast and versatile toolkit for accurate de novo assembly of organelle genomes. Genome Biology 21(1): 241. https://doi.org/10.1186/s13059-020-02154-5

Jin ZT, Hodel RGJ, Ma DK, Wang H, Liu GN, Ren C, Ge BJ, Fan Q, Jin SH, Xu C, Wu J, Liu BB (2023) Nightmare or delight: taxonomic circumscription meets reticulate evolution in the phylogenomic era. Molecular Phylogenetics and Evolution 189: 107914. https://doi.org/10.1016/j.ympev.2023.107914

Jin ZT, Ma DK, Liu GN, Hodel RGJ, Jiang Y, Ge BJ, Liao S, Duan L, Ren C, Xu C, Wu J, Liu BB (2024) Advancing *Pyrus* phylogeny: Deep genome skimming-based inference coupled with paralogy analysis yields a robust phylogenetic backbone and an updated infrageneric classification of the pear genus (Maleae, Rosaceae). Taxon 73: 784–799. https://doi.org/10.1002/tax.13163

Katoh K, Standley DM (2013) MAFFT multiple sequence alignment software version 7: improvements in performance and usability. Molecular Biology and Evolution 30: 772–780. https://doi.org/10.1093/molbev/mst010

Kearse M, Moir R, Wilson A, Havas SS, Cheung M, Sturrock S, Buxton S, Cooper A, Markowitz S, Duran C, Thierer T, Ashton B, Meintjes P, Drummond A (2012) Geneious Basic: an integrated and extendable desktop software platform for the organization and analysis of sequence data. Bioinformatics 28: 1647–1649. https://doi.org/10.1093/bioinformatics/bts199

Li M, Tetsuo OT, Gao YD, Xu B, Zhu ZM, Ju WB, Gao XF (2017) Molecular phylogenetics and historical biogeography of *Sorbus sensu stricto* (Rosaceae). Molecular Phylogenetics and Evolution 111: 76–86. https://doi.org/10.1016/j.ympev.2017.03.018

Liu BB, Hong DY, Zhou SL, Xu C, Dong WP, Johnson G, Wen J (2019) Phylogenomic analyses of the *Photinia* complex support the recognition of a new genus *Phippsiomeles* and the resurrection of a redefined *Stranvaesia* in Maleae (Rosaceae). Journal of Systematics and Evolution 57: 678–694. https://doi.org/10.1111/jse.12542

Liu BB, Campbell CS, Hong DY, Wen J (2020) Phylogenetic relationships and chloroplast capture in the *Amelanchier-Malacomeles-Peraphyllum* clade (Maleae, Rosaceae): evidence from chloroplast genome and nuclear ribosomal DNA data using genome skimming. Molecular Phylogenetics and Evolution 147: 106784. https://doi.org/10.1016/j.ympev.2020.106784

Liu BB, Ren C, Kwak M, Hodel RGJ, Xu C, He J, Zhou WB, Huang CH, Ma H, Qian GZ, Hong DY, Wen J (2022) Phylogenomic conflict analyses in the apple genus *Malus* s.l. reveal widespread hybridization and allopolyploidy driving diversification, with insights into the complex biogeographic history in the Northern Hemisphere. Journal of Integrative Plant Biology 64: 1020–1043. https://doi.org/10.1111/jipb.13246

Liu GN, Ma DK, Xu C, Huang J, Ge BJ, Luo Q, Wei Y, Liu BB (2023a) *Malus* includes *Docynia* (Maleae, Rosaceae): evidence from phylogenomics and morphology. PhytoKeys 229: 47–60. https://doi.org/10.3897/phytokeys.229.103888

Liu GN, Ma DK, Zhang Y, Hodel RGJ, Xie SY, Wang H, Jin ZT, Li FX, Jin SH, Zhao L, Xu C, Wei Y, Liu BB (2023b) Phylogenomic analyses support a new infrageneric classification of *Pourthiaea* (Maleae, Rosaceae) using multiple inference methods and extensive taxon sampling. Taxon 72: 1285–1302. https://doi.org/10.1002/tax.13083

Lu LT, Spongberg SA (2003) *Sorbus* L. In: Wu ZY, Raven PH, Hong DY (Eds) Flora of China. Vol. 9. Beijing: Science Press; St. Louis: Missouri Botanical Garden Press, 144–170. http://foc.eflora.cn/content.aspx?TaxonId=130718

McAllister H (2005) The genus *Sorbus* Mountain Ash and other Rowans. London: Royal Botanical Gardens, 252 pp.

Phipps JB, Robertson KR, Smith PG, Rohrer JR (1990) A checklist of the subfamily Maloideae (Rosaceae). Canadian Journal of Botany 68: 2209–2269. https://doi.org/10.1139/b90-288

Qu XJ, Moore MJ, Li DZ, Yi TS (2019) PGA: a software package for rapid, accurate, and flexible batch annotation of plastomes. Plant Methods 15: 50. https://doi.org/10.1186/s13007-019-0435-7

Ronquist F, Huelsenbeck JP (2003) MrBayes 3: bayesian phylogenetic inference under mixed models. Bioinformatics 19:1572–1574. https://doi.org/10.1093/bioinformatics/btg180

Ruprecht FJ (1869) Sertum Tianschanicum. Mémoires de l'Académie Impériale des Sciences de Saint Pétersbourg, Septième Série (Sér. 7) 14: 33–73. ser.7:t.14 (1870) - Mémoires de l'Académie impériale des sciences de St.-Pétersbourg - Biodiversity Heritage Library (biodiversitylibrary.org).

Schneider CK (1906) Pomaceae sinico-japonicae novae et adnotiones generales de Pomaceis. Bulletin de l'Herbier Boissier sér 2, 6(4): 311–319. [http://www.biodiversitylibrary.org/bibliography/49730]

Stamatakis A (2014) RAxML version 8: a tool for phylogenetic analysis and post-analysis of large phylogenies. Bioinformatics 30: 1312–1313. https://doi.org/10.1093/bioinformatics/btu033

Tang CQ, Chen X, Deng YF, Geng LY, Ma JH, Wei XY (2022) Complete chloroplast genomes of *Sorbus* sensu stricto (Rosaceae): comparative analyses and phylogenetic relationships. BMC Plant Biology 22: 495. https://doi.org/10.1186/s12870-022-03858-5

Wang H, Li XY, Jiang Y, Jin ZT, Ma DK, Liu B, Xu C, Ge BJ, Wang T, Fan Q, Jin SH, Liu GN, Liu BB (2024) Refining the phylogeny and taxonomy of the apple tribe Maleae (Rosaceae): insights from phylogenomic analyses of 563 plastomes and a taxonomic synopsis of *Photinia* and its allies in the Old World. PhytoKeys 242: 161–227. https://doi.org/10.3897/phytokeys.242.117481

Yü TT, Kuan KC (1963) Taxa nova Rosacearum Sinicarum (I). Acta phytotaxonomica sinica 8 (3): 202–236. [https://www.jse.ac.cn/fileup/1674-4918/PDF/1963-3-202-17472.pdf] [In Chinese]

Yü TT, Lu LT (1974) *Spiraea*, *Dichotomanthes*, *Cotoneaster*, *Sorbus*, *Chaenomeles*. In: Yü TT (Ed.) Flora republicae Popularis Sinicae 36. Science Press, Beijing, 344 pp. [http://www.iplant.cn/info/Sorbus?t=z]